Mechanical Energy Storage System

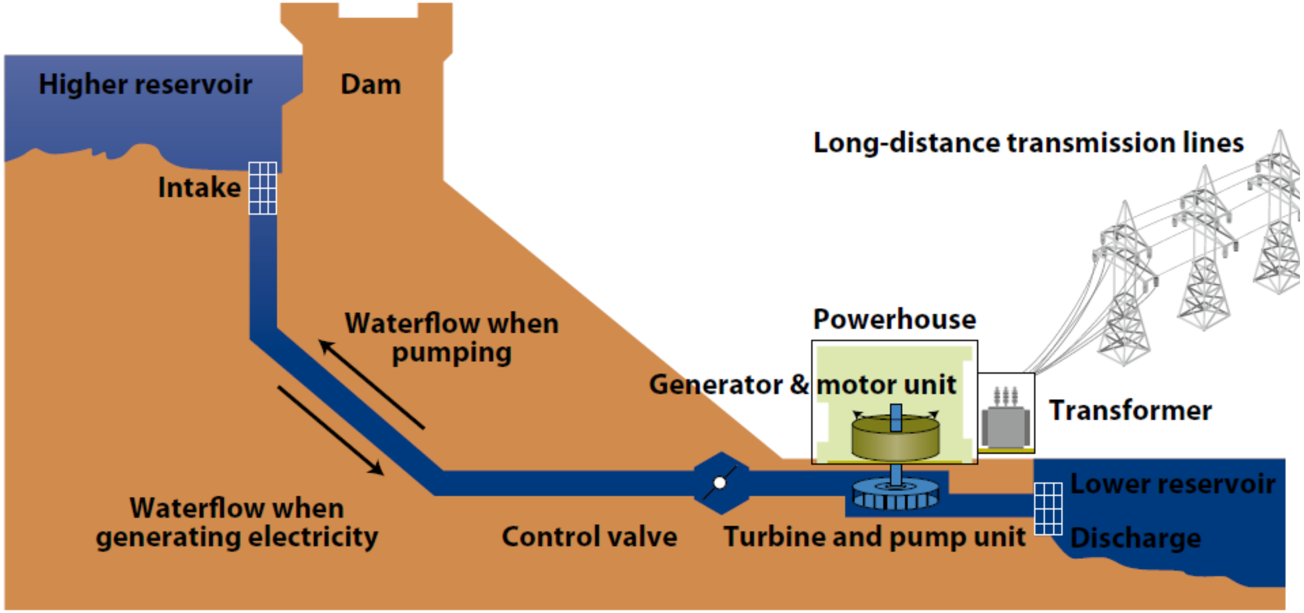
Assoc. Prof. Chittin Tangthieng

Department of Mechanical Engineering,
Faculty of Engineering, Chulalongkorn University

1. Pumped Hydro Energy Storage (PHES)

1.1 Basic Description

- Gravitational potential energy storage
- Two water reservoirs at different elevations
- Pumping to the upper reservoir (charging)
- Generating electricity to the lower reservoir (discharging)

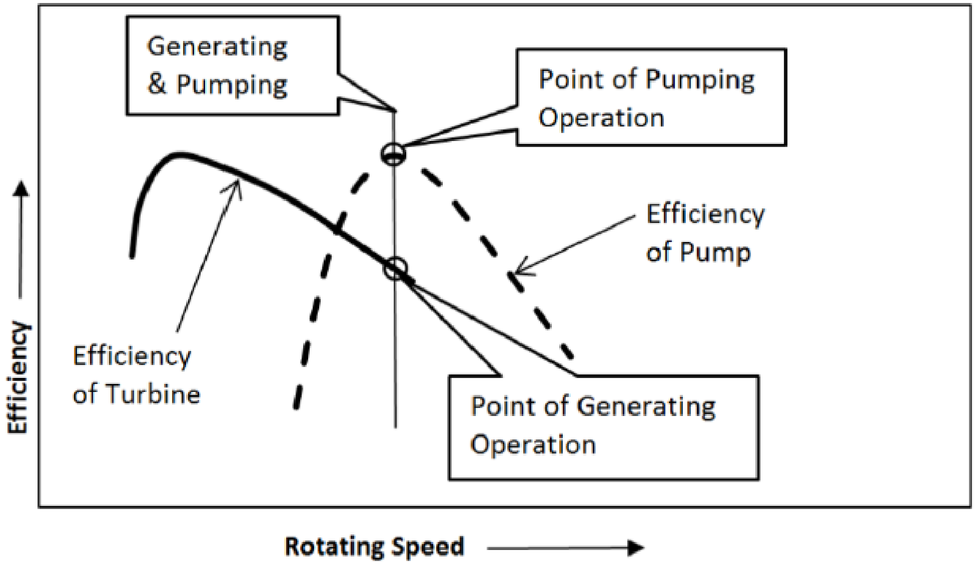


1.2 Technical Aspects

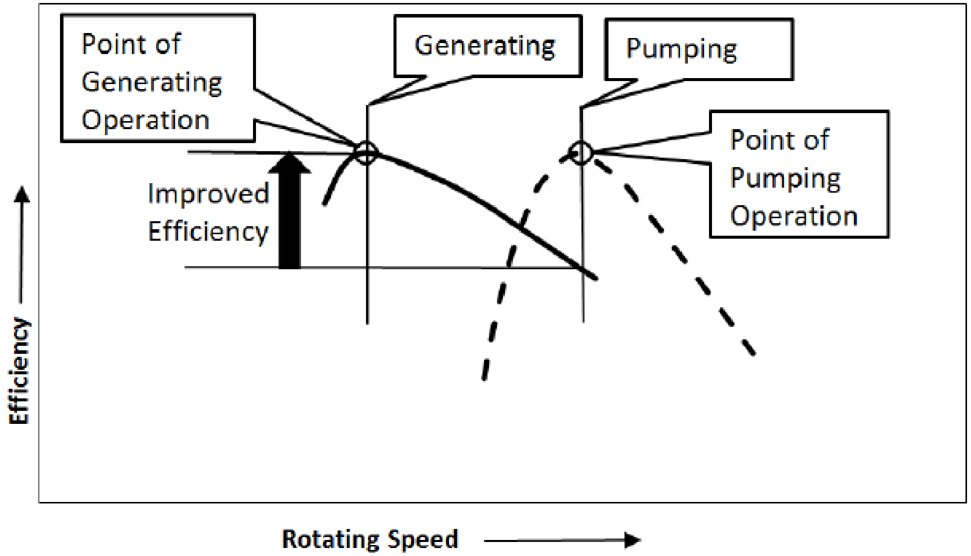
- Energy density: 0.2-2 Wh/L
- Power density: 0.1-0.2 W/L
- Typical discharge time: hours
- Response time: minutes
- Round trip efficiency: 70-85%.
- Lifetime: 60 year on average
- Cycle lifetime: 50,000 cycles on average
- Self discharge: 0.01% per day on average
- Rated capacity: up to 4,000 MW
- Capital cost: 5-100 $/kWh (21 $/kWh on average) in 2016
  5-100 $/kWh (21 $/kWh on average) in 2030

1.3 General Information

- It accounts for 172.5 GW or 90.3 % of all active storages with a capacity of 191.1 GW (2020) mainly in China, Japan and USA.
- A majority of modern PHES plants use reversible pump/turbine units.
- Variable speed control for a pump/turbine unit can be implemented to improve the plant efficiency.



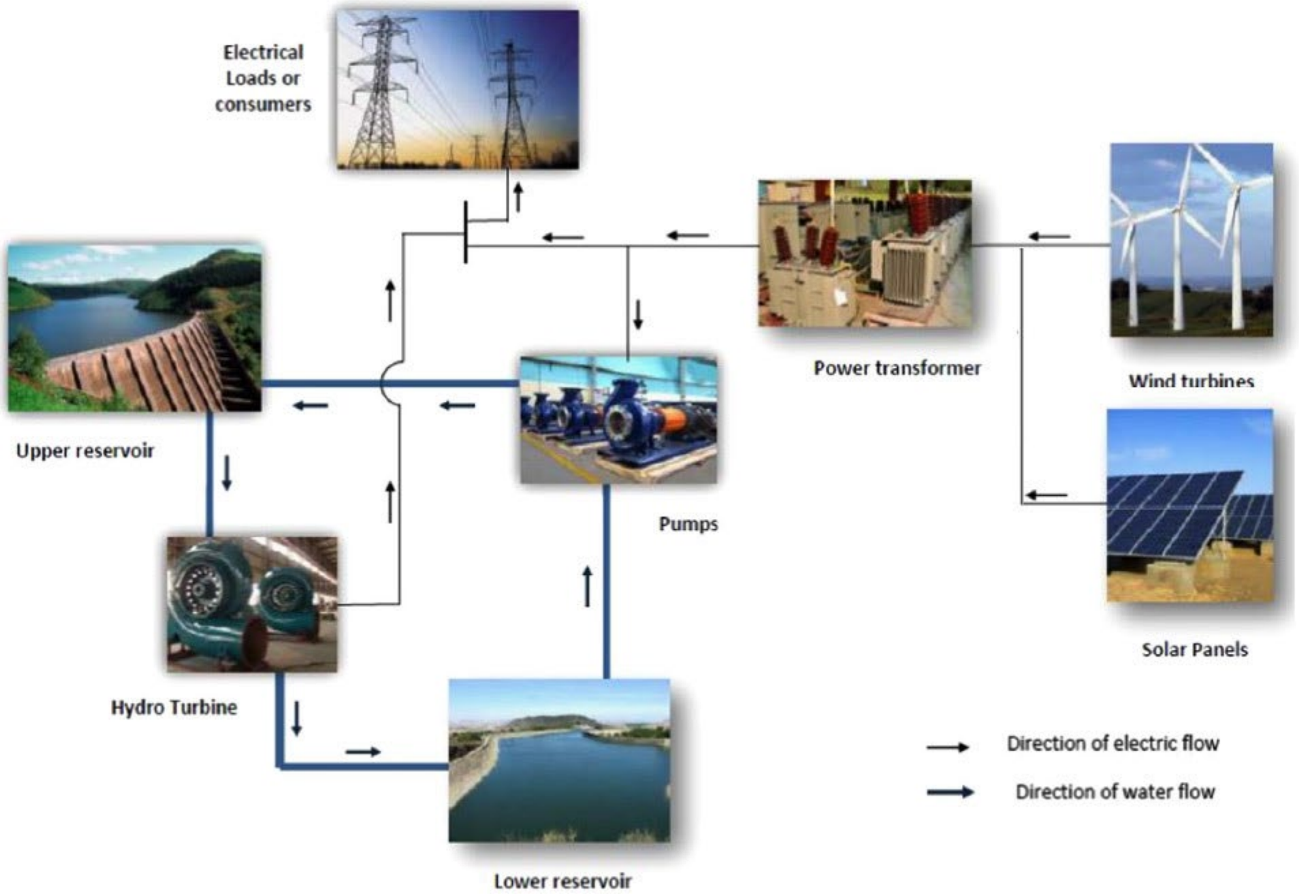
Fixed speed unit



Variable speed unit

1.4 Applications

- Energy shifting due to fluctuating power demand
- Energy shifting due to variable power sources from renewable energy
- Power quality
- Energy reserve



PHES system integrated with renewable energy sources

1000-MW Lamtakong Jolabha Vadhana Power Plant,
Nakhon Ratchasima, Thailand

2172-MW PHES plants, Ludington, Michigan, USA

1060-MW Goldisthal PHES plant,
Goldisthal, Germany

1600-MW Kazunogawa PHES plant,
Koshu, Japan

30-MW Okinawa Yanbaru Seawater PHES plant, Okinawa, Japan

1.5 Advantages/Disadvantages

Advantages

- Mature technology
- Very low self discharge
- Very long lifetime / long cycle lifetime
- Large capacity with long storage period

Disadvantages

- Geographical limitation
- High capital cost and long project construction period
- Low energy and power density
- Environmental concern

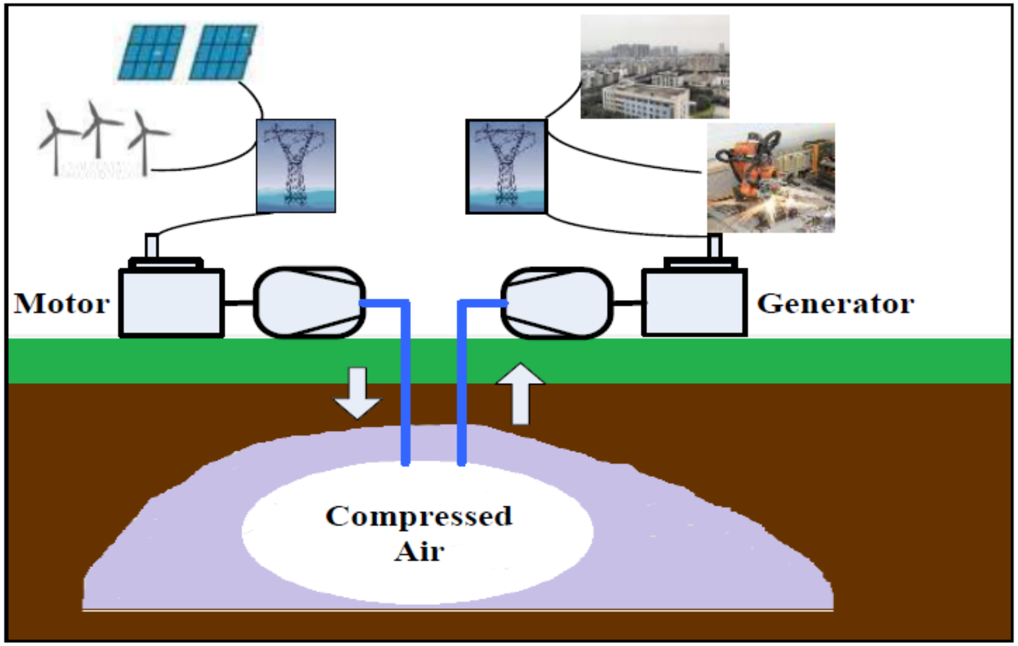
1.6 Potential Technologies

- Seawater: isolated island and offshore wind farm
- Underwater reservoirs: avoid land use and offshore wind farm
- Underground reservoirs: abandoned mines
- Small-scale PHS system: renewable energy source at remote area

2. Compressed Air Energy Storage (CAES)

2.1 Basic Description

- Air internal energy storage
- Compressors, turbines , and cavern (reservoir)
- Air compression to the cavern (charging)
- Air expansion from the cavern (discharging)

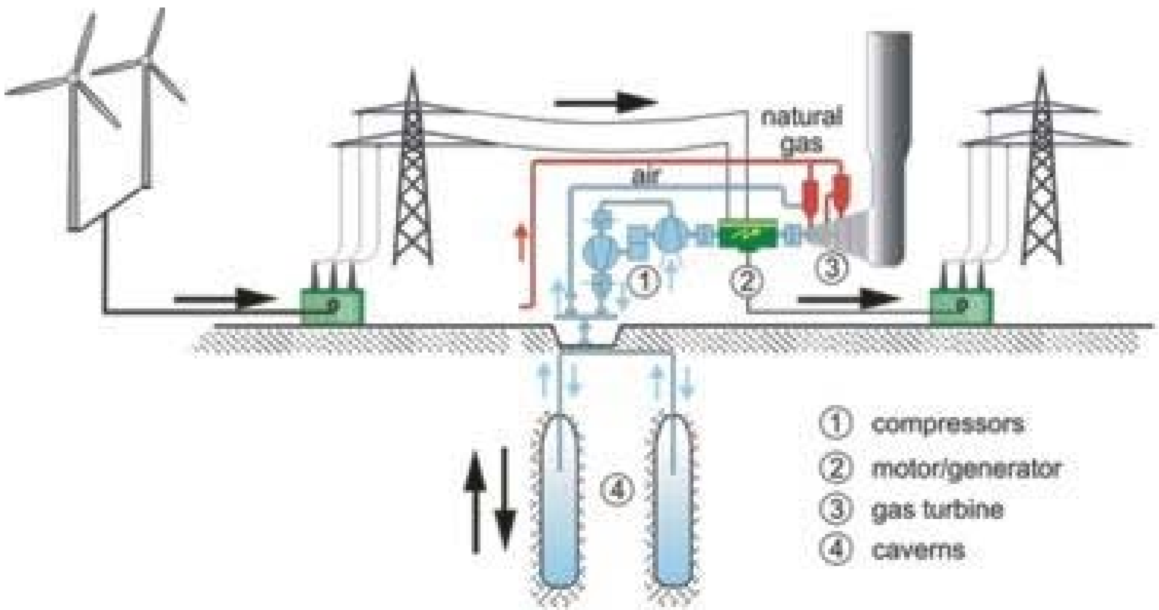


2.2 Technical Aspects

- Energy density: 2-6 Wh/L
- Power density: 0.2-0.6 W/L
- Typical discharge time: hours
- Response time: minutes
- Round trip efficiency: 40-55% for diabatic CAES
: 50-70% for adiabatic CAES
- Lifetime: average 50 year on average
- Cycle lifetime: average 50,000 cycles on average
- Rated capacity: up to 300 MW
- Self discharge: 0.5% per day on average
- Capital cost: 2-84 $/kWh (53 $/kWh on average) in 2016
2-71 $/kWh (44 $/kWh on average) in 2030

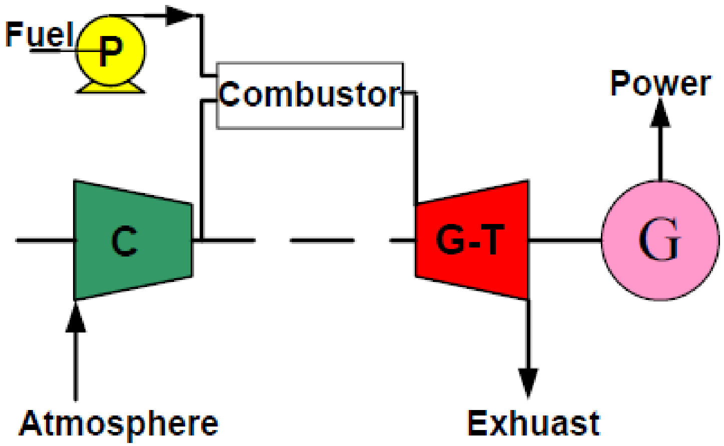
2.3 Applications

- Energy shifting due to fluctuating power demand
- Energy shifting due to variable power sources from renewable energy
- Power quality
- Energy reserve

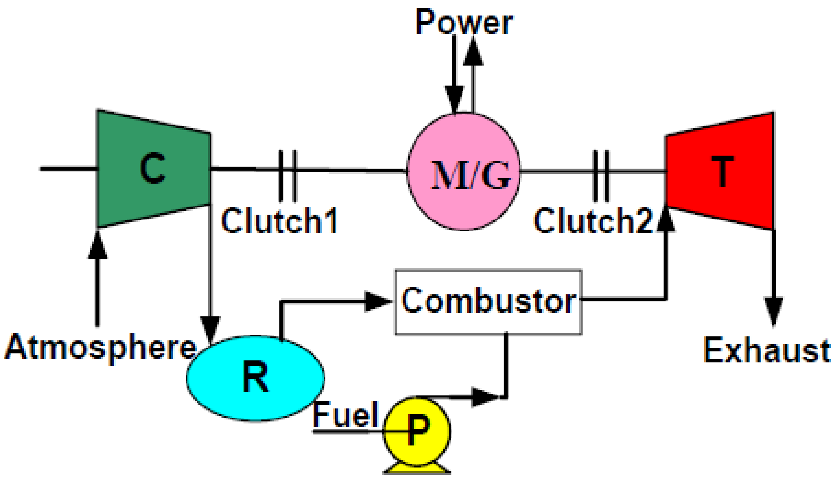


2.4 Types of CAES

1) Diabatic CAES system (DCAES)

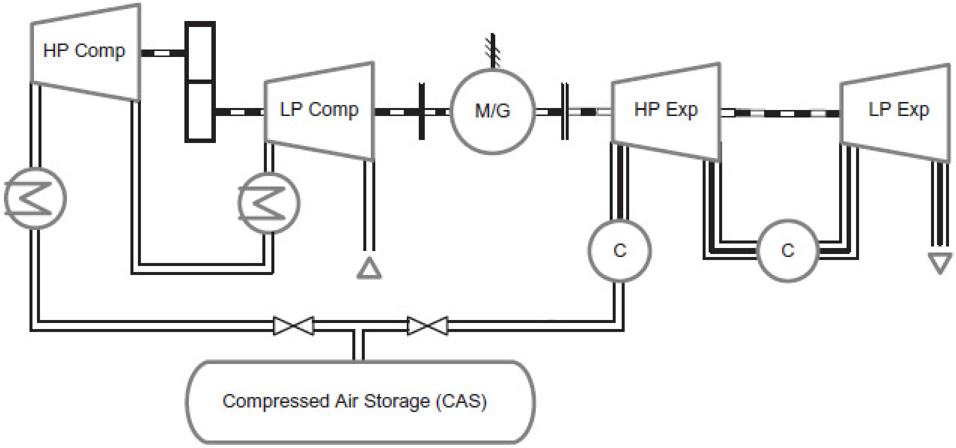


Standard GT power plant

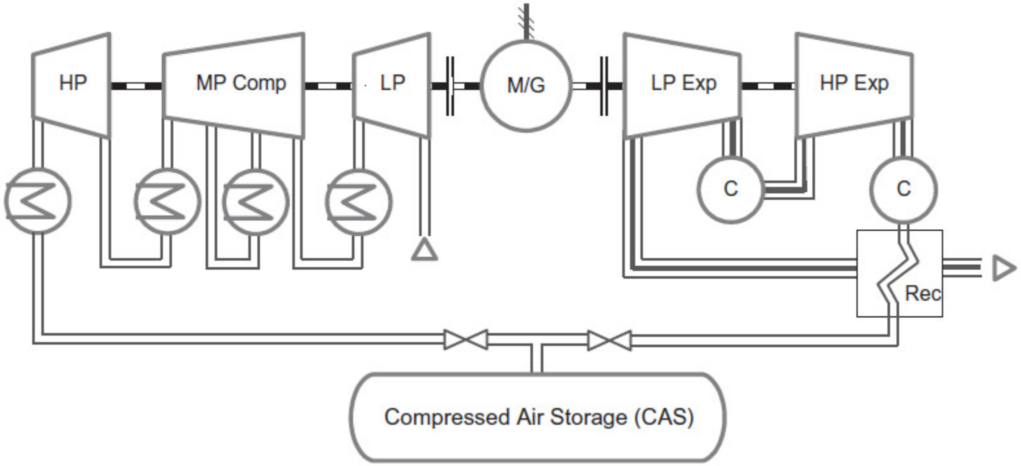


Diabatic CAES system

- Compressor and turbine are decoupled.
- During the off-peak period, air is compressed, cooled, and sent to the cavern (reservoir).
- During the peak period, the stored air runs the gas-fired turbine generator.

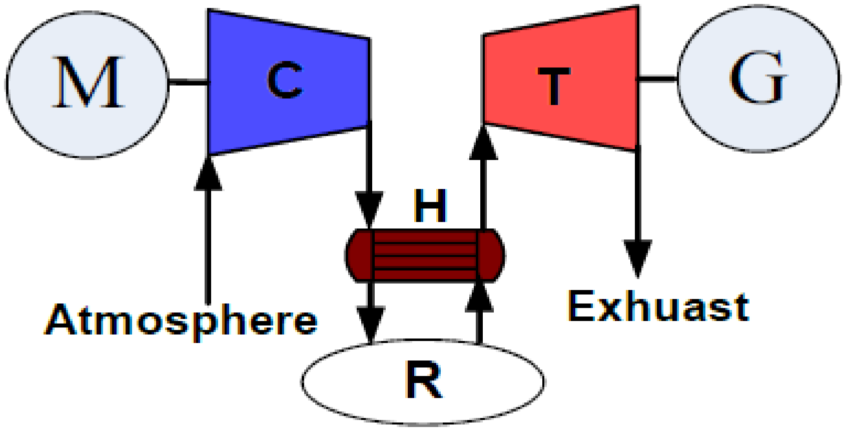


290-MW Huntorf DCAES plant, Germany



110-MW Mcintosh DCAES plant, Alabama, USA

2) Adiabatic CAES system (ACAES)

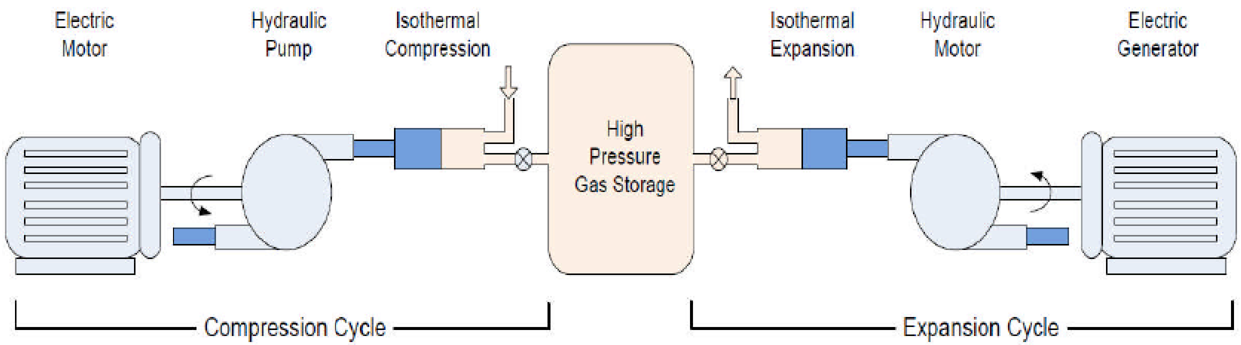


- Combustion process is not required, resulting in no direct CO_2 emission.
- Thermal energy storage or TES (shown as "H" in the figure) is utilized to store thermal energy from the compressed air and release this energy back during the air expansion. It could be a conventional TES or porous media.
- The approximate round trip efficiency is approximately 70% (Simulation).

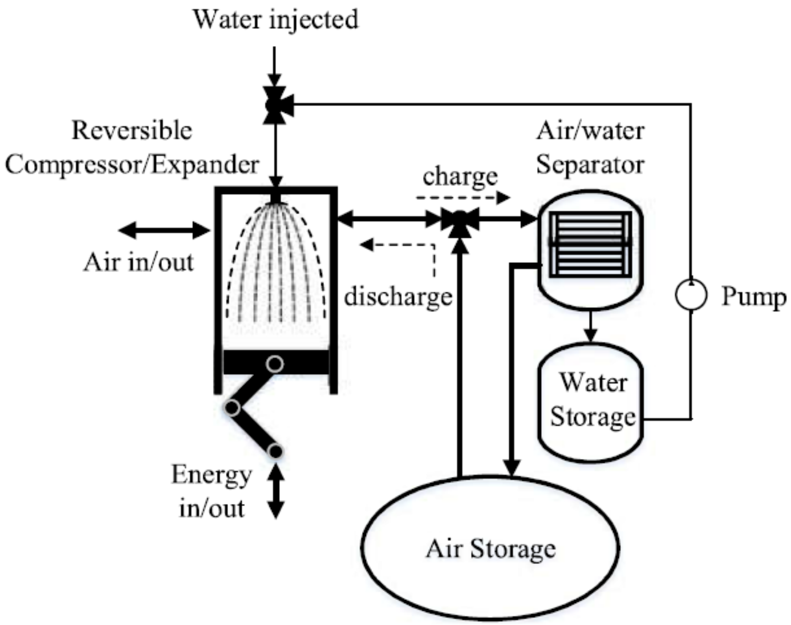
0.5-MW ACAES pilot plant (TICC-500 plant),

Tsinghua, China

3) Isothermal (or Near-Isothermal) CAES system



- Compression work is minimized and expansion work is maximized through isothermal compression/expansion.
- The finned piston with cooling media is used for an effective heat transfer.
- The system is at a low speed.
- It is practical for a small scale plant and still under development.



2.5 Advantages/Disadvantages

Advantages

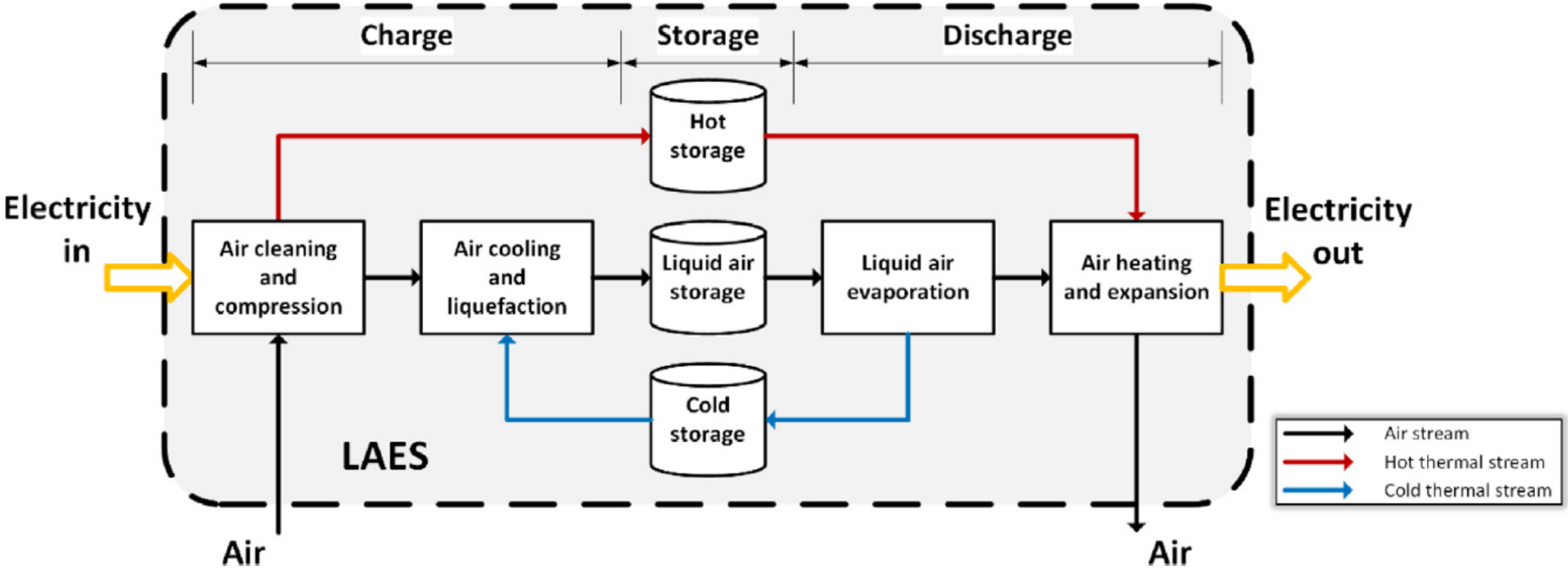
- Very long lifetime / long cycle lifetime
- Large capacity

Disadvantages

- Geological constraint
- High capital cost and long project construction period
- Low energy and power density
- Low round trip efficiency

2.6 Potential Technologies

- Liquid air energy storage (LAES): no geological constrain
- Supercritical compressed air energy storage (SCAES): no geological constrain
- Improve thermal energy storage performance for adiabatic CAES or improve cold thermal energy storage performance for LAES
- Combine LAES with other units or Hybrid-LAES
- Other types for turbine/expander such as screw, scroll, rotary vane.



Standalone LAES Processes

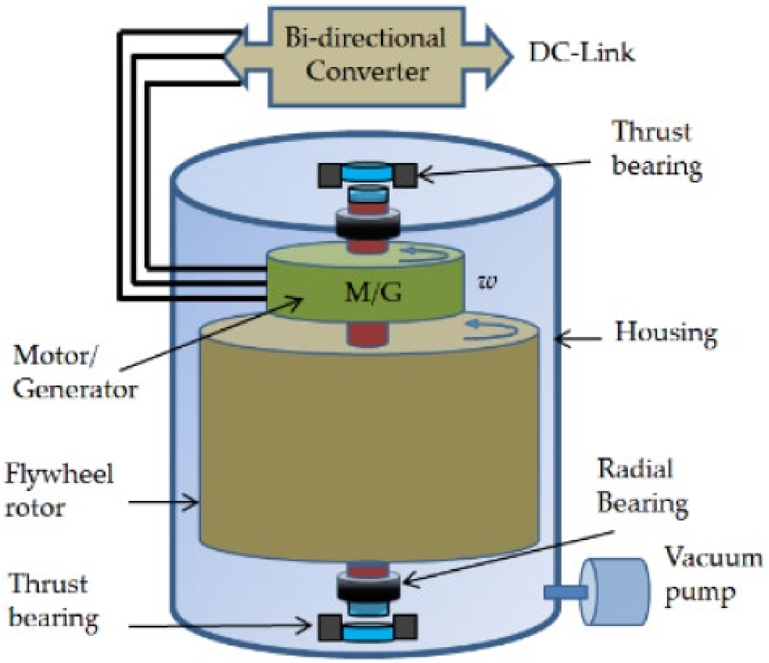
350-kW LAES pilot plant, Birmingham, UK

5-MW LAES demonstration plant, Manchester, UK

3. Flywheel Energy Storage (FES)

3.1 Basic Description

- Rotational kinetic energy storage
- Rotating disk (flywheel) in a chamber
- Increasing the angular velocity (charging)
- Decreasing the angular velocity (discharging)



3.2 Technical Aspects

- Energy density: 20-80 Wh/L
- Power density: 5,000 W/L
- Typical discharge time: seconds/minutes
- Response time: less than a second
- Round trip efficiency: 80-90%.
- Lifetime: 20 year on average
- Cycle lifetime: 200,000 cycles on average
- Rated capacity: 0.1-20 MW
- Self discharge: 60% per day on average
- Capital cost: 1,500-6,000 $/kWh (3,000 $/kWh on average) in 2016
  979-3917 $/kWh (1959 $/kWh on average) in 2030

3.3 Applications

- Power quality (frequency regulation)
- Energy shifting due to fluctuating power demand (short term)
- Energy shifting due to variable power sources
- Short term energy reserve

3.4 Types of FES

- Low speed (up to 10,000 rpm)
  - Mechanical or magnetic bearings
  - Heavier material such as steel
  - Cheaper
  - Lower efficiency and cycling characteristics
- High speed (10,000 to 100,000 rpm)
  - Magnetic bearings
  - Strong but lighter composite material
  - Approximately 5 times more expensive
  - Higher efficiency and cycling characteristics

20-MW FES plant, Stephentown, NY, USA

2-MW FES unit at metro substation, LA, USA

800-MW FES unit, Joint European Torus, UK

2-MW FES system at Kodiak Island, Alaska, USA

3.5 Advantages/Disadvantages

Advantages

- Fast charge capabilities
- Long lifetime / very long cycle lifetime
- High power density

Disadvantages

- Short discharge time
- High self discharge
- Low energy density (compared to battery)
- Safety concern

3.6 Potential Technologies

- Disk material: lighter weight and more strength
- Ultra high speed FES
- Superconductive magnetic bearing

End of presentation

Thank you for your attention